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Froth Flotation in Cement Manufacture.

By the courtesy of Mr. G. K. Engelhart, of the Valley Forge Cement Company, Catasauqua, U.S.A., we are able to give further details of the flotation process, reference to which was made in the June number of this journal. The froth flotation process was discovered and developed in the works of the Valley Forge Cement Company. Mr. Engelhart writes:

Froth flotation is now being used as the principal step in a process for deriving cement raw material mixtures of correct chemical and physical composition, for the manufacture of all known types of cement, from available materials which either may be inferior or actually unusable in conventional manufacture. The complete process involves a combination of grinding, classification, flotation, and thickening methods, each adapted to satisfy the specific requirements of cement and the peculiar characteristics of calcareous and argillaceous minerals. The purpose is to correct the proportions of the mineral sources of the four oxides essential for Portland cement and, when they are present, to remove proportions of harmful or useless impurities. The corrections are made by removing excess proportions of one or more minerals or proportions of undesirable minerals occurring naturally in the available materials.

Seven cement mills are now using the process, and the preliminary work has been completed for several others. The process was invented by Mr. Charles H. Brerewood and first applied by him to the plant of the Valley Forge Cement Company at West Conshohocken. Since March, 1934, all of the cement produced at this plant has been manufactured by this process. Although several descriptions have been published they relate largely to the earlier operations and are incomplete, particularly as to improvements of interest to the cement manufacturer which may tend to broaden the field of minerals separation and offer new means for the recovery or purification of other industrial minerals.

There is an extensive literature in technical publications and patents on the agitation froth process, but it is largely limited to the concentration of metallics, particularly the sulphides. Weinig and Carpenter,¹ in common with other authorities, generally characterise the flotation of oxidised ores as being not so important as that of the sulphides with relation to tonnage, to the low unit value of the contained minerals in some of them, and to the fineness to which they must be ground, which "makes the fine grinding necessary for flotation economically impossible." The flotation of siliceous or acid minerals is of more recent origin and probably would be considered even less important than that of the oxides. However, the description of the raw materials of the Valley Forge plant and its flow sheet show that separations can be made by froth flotation well within the range of practical economics, even though they are from materials ground to a fineness far beyond anything previously contemplated by the flotation chemist and from the material of the lowest commercial value of any subjected to mineral separation methods.

Flotation Reagents.

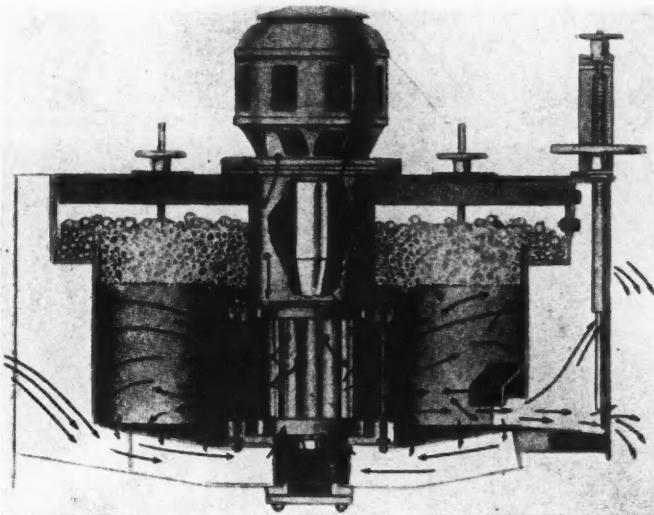
A wide variety of flotation agents and reagents has been found to be useful in the treatment of argillaceous limestone pulps, but the quantities used and the methods of control are unusual. The successful differential separations are largely due to the use of limited quantities of collecting reagents introduced in small increments in stage-oiling circuits.

The typical frothers—mixtures of monohydric alcohols, dilute resinates, and cresylic acid—are satisfactory. The quantities required are low and are introduced at various points in the circuit to maintain the desired froth balance. At Valley Forge a total of 0.04 lb. of the alcohol frother per ton of rock, suspended in about 4 tons of water, is sufficient for the entire circuit. The major portion of the water of the pulp is returned to the flotation circuit, which accounts in part for the economy in consumption.

The usual collecting reagents or promoters for oxide ore minerals may be employed—namely, unsaturated fatty acids, resin acids, and their soaps and emulsions (i.e. substances which in solution release a fatty or resin acid radical). Resin acids are generally inferior collectors, but at least one mixture of resin and fatty acids appears to have unusual efficiency⁴. The common oxide mineral collectors are oleic acid, fish oil fatty acids, and their emulsions and soaps, and refined talloel², which is a mixture of fatty and resin acids derived from the black liquor soap of the sulphate process for the manufacture of paper. Talloel soap³ and emulsions^{4,5} are effective collectors of calcite. Some soaps which are useful for certain argillaceous limestone pulps have definite frothing characteristics; these collectors are usually saponified fatty and resin acids, at least one of which³ requires no separate frother under appropriate conditions. In general, the emulsions are more satisfactory than the soaps in the flotation of calcite, the common mineral form of calcium carbonate, since, in the differential separation of this mineral, soaps sometimes create an excessive and comparatively barren froth. Unmodified fatty acids of high titer are generally unsatisfactory

for use in the usual argillaceous limestone pulps, in view of the difficulty in feeding them in small increments to each cell of a stage-oiling circuit and dispersing them rapidly throughout the flotation pulp.

The successful concentration of calcite from the siliceous minerals in these finely divided pulps is principally the result of adding the collecting reagent in extremely small quantities to each cell of the circuit. The total quantity of collecting reagent used at the Valley Forge plant is about 0.5 lb. per ton of feed; this quantity is only about one-fifth to one-tenth of that used in the flotation of the much coarser phosphate pulps. In the flotation of phosphate, for example, the usual practice is to add fatty acid and a mineral oil, together with an excess



Flow Diagram of a Fagergren Subaeration Flotation Machine (Cell).

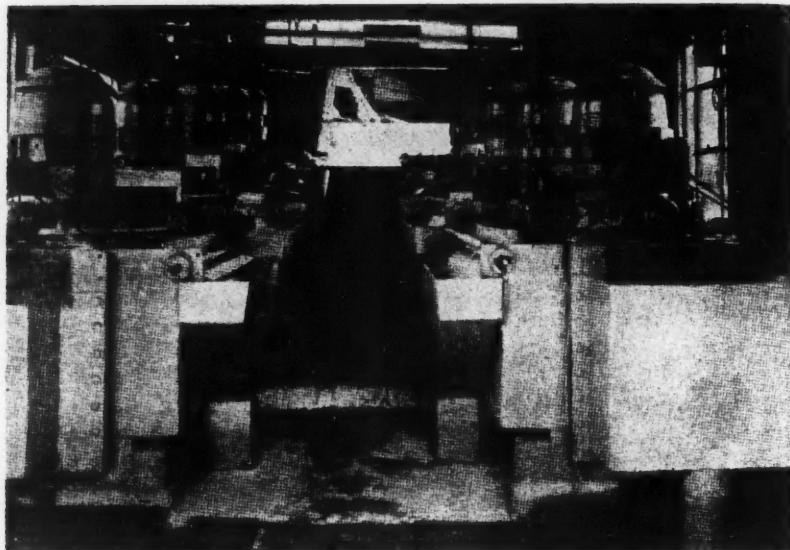
The flow of the mineral pulp is indicated by plain arrows. The flow of air induced by the rotor is shown by arrows terminating in circles.

of sodium hydroxide beyond that necessary to saponify the fatty acid, and to mix it with a dense pulp prior to dilution and concentration by flotation. If mineral oils are used with fatty acids they are generally undesirable in the flotation of limestone pulps, since they tend to promote heavy flocculation, but when dispersed in an emulsion of a soap they tend to reduce excessive frothing⁵.

The collectors for the siliceous minerals are described by Lenher⁶ as those which give in solution the long-chain surface-active group in the positive ion and in which the negative ion is usually a halogen. They are variously called "aliphatic amines," "positive ion," or "cationic" reagents. They modify the surfaces of the siliceous mineral grains with limited filming of the oxides. Many of the amine reagents have a critical pH range and are ineffective in alkaline

pulps. However, the principal members of the class described by Lenher are highly efficient in pulps in which the alkalinity ranges from pH 7.4 to 8, the normal limits of alkalinity of cement raw material pulps.

Breerwood and Williams⁷ discovered that the reagents which they preferred in this class, when used in normal minimum quantities of about 0.4 lb. per ton of feed and sometimes considerably less, would float all or substantially all of the mineral constituents, including the acidic, oxide, and sulphide minerals present in argillaceous limestone pulps; but they also found that by carefully limiting the quantities and by introducing very small increments at each step in a stage-oiling circuit, differential separations can be made, silicates being readily separated



Calcite Flotation Circuits at the Plant of the Valley Forge Cement Company.

The cells of each row are in series. Feeders for stage oiling the reagents are visible behind the motors. The rake classifier at the rear separates fine mica from the tailings.

The mica flotation circuit for the rake underflow is beyond the rake.

from silica and calcite. For example, these carefully limited quantities may be as low as 0.05 lb. per ton of feed, the total quantity of cationic reagent used at Valley Forge for the concentration and removal of the micas. Further, the micas and talc may be separated as a concentrate to be discarded, to recover the calcite, quartz, and composite rock particles as a tailing of flotation. A sulphide such as pyrite, commonly believed to be floated only by reagents of a different class, can be removed with the silicates without substantial loss of quartz. Under careful control silicate minerals, such as the micas and talc, can

be separated from feldspars, quartz, and calcite. It is believed that the operations at the Valley Forge plant are the first commercial use of reagents of this general class; the preferred reagent is a mixture of similar compounds in which dodecyl amine hydrochloride is the principal constituent.

In addition to frothers and collectors, reagents with various functions are frequently useful. Dispersers are especially useful in finely divided argillaceous limestone pulps to reduce natural flocculation and colloidal filming and thereby improve both flotation and classification. In these complex pulps, calcium lignin sulphonate has been the most effective, either alone or with additions of sodium silicate or soda ash^{8,9}. Depressors are used to decrease floatability of an undesired mineral; e.g. calcium lignin sulphonate, effective as a disperser, also depresses carbon in various mineral pulps and overcomes its tendency to cause flocculation and to consume disproportionate quantities of both fatty acid and cationic reagents¹⁰.

There are two theories as to the action of collecting reagents on the surfaces of the mineral grains which they concentrate. The subject is highly controversial and is referred to only with relation to the practical effects that take place in a flotation cell. The chemical theory assumes a chemical reaction (a metathesis) between the anion of a fatty acid, for example, and the hydrolysed surface of the oxide ore mineral to produce an oriented monomolecular film of insoluble metallic soap—e.g. calcium oleate. The adsorption theory supposes a surface tension difference at the solid-liquid interface, in which a surface-active part of the collector unites with the hydrolysed surface of the mineral grain. In any case, the ore mineral particle is at least partially filmed, which makes the surface water repellent and accordingly subject to air-bubble attachment.

The mechanics of froth flotation comprise air-bubble attachment to the water-repellent surfaces of the ore minerals. These bubbles are considered to be re-formed from solution at the water-solid interfaces. In sulphide flotation, and possibly in the flotation of coarse oxide ore mineral aggregates such as Florida phosphate, the air bubbles are said to be relatively large, the ore particles adhering to them and being floated to the surface of the pulp like a basket attached to a balloon. At the surface the particles and bubbles attach themselves to the froth bubbles, are stabilised by the frothing agent, and overflow as the concentrate. In the concentration of calcite from argillaceous limestones the mechanics are quite different, particularly because of the extreme fineness of the particles and the nature of air-bubble attachment. The air bubbles attached to the calcite grains are so fine that they cannot be seen at magnifications as great as 150 diameters owing to movements attributable to surface tension. A number of grains of calcite may be seen bound together in groups in the form of air bubble-mineral floccules, in which the particles are each surrounded and bonded by air bubbles in an increasing order of sizes from the grain surfaces; the air entrained in each floccule causes it to rise and attach itself to a large froth bubble on the surface of the cell.

Materials Used.

At the Valley Forge plant compositions for all known types of Portland cement can be produced solely from the argillaceous limestone quarried on the site, but the flexibility of the Breerwood process makes it possible to substitute a small quantity of additional silica for the manufacture of special high silica-low alumina cements without going to extremes in mineral separation. With relation to any modern type of cement, the rock is deficient in calcite and uncombined silica, excessive in total silica and alumina, and satisfactory as to iron, although part of the iron occurs as pyrite which is not wholly desirable in view of its sulphur content. The principal minerals are calcite, quartz, muscovite mica, phlogopite mica, feldspar, limonite, pyrite, pyrrhotite, and dolomite; all of these which are not magnesian compounds are useful in cement manufacture.

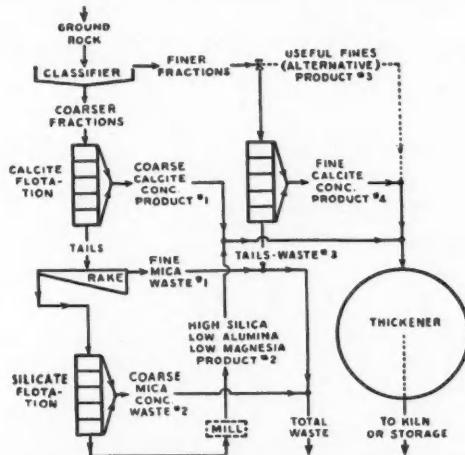
The removal of a micaceous concentrate, comprising a relatively negligible proportion of the total tonnage, is sufficient to correct the deficiency in calcite, to correct the deficiency in uncombined silica for ordinary types and to permit its substitution in part for special cements, to remove the excess of alumina, to decrease satisfactorily the proportion of magnesia, and similarly to reduce the proportion of the alkalis, which in these materials are combined with the micas. Since these materials are typical of complex argillaceous limestones and because the flow sheet employed is more complete than those in use in other plants, a detailed description of the flow sheet will be given to illustrate what has been accomplished and what significance the process may have with relation to other minerals.

Flow Sheet.

The present operations at the Valley Forge plant involve a combination of oxide mineral and silicate flotation, in which classification plays an important part. This practice results in the necessary reduction of the alumina and magnesia to permit the production of low heat of hardening and sulphate-resisting cements. In a circuit recently found to be most effective (see page 119) the minerals are ground to about 90 per cent. of -200-mesh material; this is sufficiently fine to free physically enough of the constituents (especially the micas) to permit the necessary subtractions. The ground materials, at an average rate of 1,300 tons a day, are classified in a hydro-separator, sometimes to provide a controllable proportion of argillaceous materials to form a part of the composition for standard cement, but principally to provide two fractions of limited particle-size ranges to be concentrated in separate flotation circuits. By limiting the particle-size ranges, cleaner concentrations can be made in differential separations from mineral pulps of this general character. The coarser fractions are subjected to rougher flotation in the presence of a frothing agent and a fatty-acid-type collecting reagent; the concentration is made in a controlled stage-oiling circuit in the presence of a total of 0.5 lb. of the fatty acid per ton of feed. This concentrate is the first completed product of the process. The tailings of this operation are hydraulically classified to take advantage of the slow sedimentation rate of mica particles, which is about half that of other mineral

particles of the same maximum diameter, to remove the finer suspended micaceous matter as an overflow^{8,9} which forms the first waste product. The underflow of the tailings classifier is subjected to flotation in a stage-oiling circuit in the presence of a total of 0.05 lb. per ton of feed of a cationic flotation reagent, which concentrates the remainder of the free micas and the pyrite in the froth. This froth concentrate is the second waste product; the tailings of this operation are the second recovered product of the process, but they require further grinding to make them suitable for burning.

Except when compositions for sulphate-resisting cements are being prepared, when all of the finer fractions are subjected to flotation, a part of the first classifier



Flow sheet of the Minerals Separation Plant of the Valley Forge Cement Company.

Recovered materials are indicated as products 1 to 4.
Rejects are indicated as wastes 1 to 3.

overflow is required as a source of argillaceous minerals and is delivered to the thickener as the third recovered product of the process. The remainder of the finer fraction is subjected to flotation in a rougher circuit in the presence of a fatty-acid-type collector to produce a calcite concentrate which forms the fourth recovered product. The tailings of this operation are highly micaceous and so low in calcite that they are discarded as the third waste product. All of the recovered products are continuously delivered to the thickener and recombined to form the ultimate mixture or the major proportion of a mixture to be completed finally by the addition of a small quantity of silica.

The micaceous matter can be subtracted exclusively by the use of the cationic reagent⁷; but as calcite tends to abstract substantial quantities, and losses of useful minerals are increased, the practice described is much more economical,

TABLE I
ANALYSIS OF VALLEY FORGE ROCK AND ITS PRODUCTS

Minerals, per cent.		Product Analysis*, per cent.				
		SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaCO ₃	MgO
Calcite	62.0	Feed	17.7	2.02	4.74	67.5
Quartz	11.0	Product 1 ..	4.7	1.9	1.5	86.0
Muscovite	11.0	Product 2 ..	36.3	2.0	3.9	59.5
Phlogopite	4.0	Product 4 ..	5.0	1.9	1.6	85.8
Limonite		Waste 1 ..	44.5	2.6	14.5	26.4
Pyrite	2.02	Waste 2 ..	44.7	4.0	16.5	18.5
Pyrrohotite		Waste 3 ..	49.9	2.3	17.4	17.6
Dolomite	10.0	Combined recovery	8.5	1.9	1.8	81.5
		Combined reject	47.0	2.9	15.5	20.0
						4.4

* Sources of oxides: SiO₂, quartz 11 per cent., muscovite 4.97 per cent., phlogopite 1.73 per cent.; Al₂O₃, muscovite 4.25 per cent., phlogopite 0.49 per cent.; CaCO₃, calcite 62 per cent., dolomite 5.44 per cent.

particularly because these reagents are more expensive than the fatty acids and their derivatives, and the controls are more flexible.

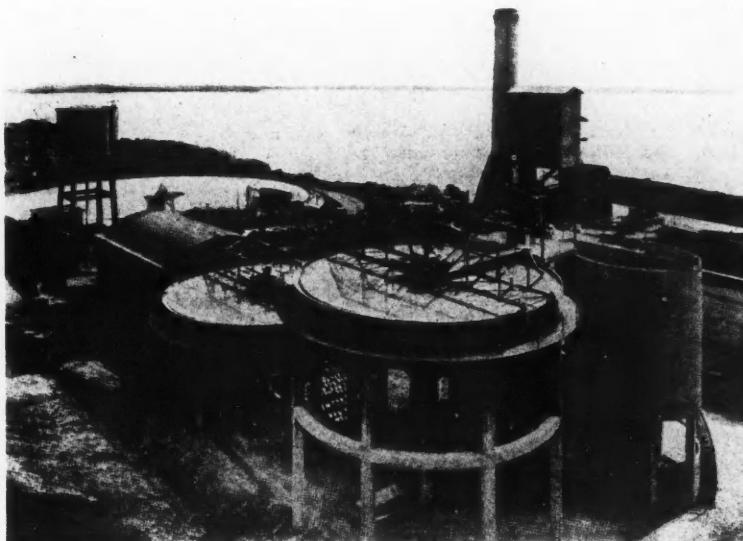
The approximate mineral content of typical Valley Forge rock, but of somewhat lower calcite grade than the average, and the oxide analyses of the principal products from processing it as described, are given in *Table I*. The recoveries illustrate the extremes to which separations must be made to permit the manufacture of sulphate-resisting cement, the most difficult type to produce. The combined recovered products are deliberately made about 5 per cent. above the desired ultimate mixture in calcium carbonate to permit the addition of high-ratio silica, e.g. sand; or if higher alumina cements are to be made some of the hydrosePARATOR overflow (product 3) may be mixed with the other recoveries to produce the ultimate mixture. The losses in silica in the rejects are partly due to its combination in the micaceous matter, in which the ratio of silica to alumina is about 1.5 to 1, and partly to incomplete mineral bond breakage, which is also the principal reason for the loss in calcite. The relatively small tonnage and limited value of these two useful constituents in the rejects would not warrant the cost of finer grinding and further processing.

Recoveries from Slimes.

Probably the most important accomplishments are the successful flotation concentrations and recoveries from pulps having the fineness of 100 per cent. of -44μ (325-mesh) and 60 per cent. of -10μ material; the problem is also sometimes complicated by the presence of graphitic carbon. The most interesting example of this class of material is the "blue limestone" or "cement rock" of the Lehigh Valley district⁸⁻¹⁰. Crystallisation is extraordinarily fine, mineral bond breakage in the pulverised material being substantially complete only in the fractions finer than about 20μ . Chemically the composition is equivalent

generally to the Valley Forge limestone, but additional mineral forms are present. Some of the alumina is present in kaolin, and a part of the magnesia occurs as talc. Petrographic identification is difficult in view of the fineness and the wide dispersion of colloidal graphitic carbon, which forms from 0.5 to 1 per cent. of the total weight. In appearance the natural rock resembles slate.

It was discovered that the silicates, including the kaolin, talc, and micas, were physically free and considerably increased in proportion in the finest fractions of the ground rock. Mr. Breerwood took advantage of this fact and developed a unique application of his process⁸ which reversed the original flow diagram



Separation Plant of Cia Argentina de Cemento Portland at Paraná.

Hydroseparators appear in the foreground, the cell house and thickener in the background, and the kiln at the extreme right.

used at the Valley Forge plant but retained the advantage of subjecting to flotation only a limited proportion of the total material supply.

Although mineral bond breakage is incomplete in the coarser fractions, the composite particles in these fractions are largely calcite and quartz. Since the rock is deficient in both of these minerals, and since in the composite particles they are in perfect contact for reaction in burning, there is no reason why they should be separated. The materials need be ground only to normal fineness and then classified to separate these coarser fractions as the first recovered product. The finer fractions may then be subjected to flotation in circuits substantially similar to those previously described; however, somewhat greater care must be taken in the control of the quantities of reagents added, which in this case are

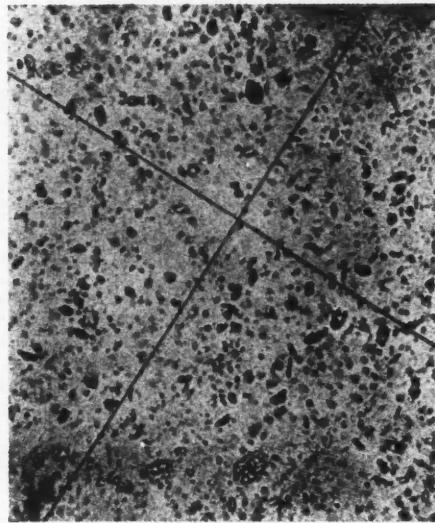
introduced in dilute form either as soaps or emulsions, if the calcite is to be concentrated. The pulps are readily amenable to flotation with dilute cationic reagents which may be used to concentrate the mica either from the original pulp or from the tailings of calcite flotation. If either type of flotation is to be efficient, preliminary steps must be taken to overcome the carbon. Two methods have been discovered for this purpose. The carbon may be removed by concentration as a froth in the presence of a frothing agent only⁸; this concentrate is valueless since it contains substantial proportions of fine silicates and represents very little weight. After the removal of the carbon, the pulp is readily amenable to flotation. A preferred alternative consists in adding up to 2 lb. per ton of a depressing agent. The most effective agent is calcium ligninsulphonate which is added at the blunger or in the feed to the first rougher cell. (Calcium ligninsulphonate is also effective in the flotation of carbonaceous precious metal and sulphide ores¹⁰.) If the calcite is concentrated, the tailings of flotation may be classified to separate the silicates from the quartz, which is recovered and combined with the concentrate and the coarser fractions of the first classifier⁸.

Based upon both pilot-plant and full-scale commercial work, one plant started operating with this process last winter, and similar plants have been designed for several other Lehigh Valley mills.

Economics of Processing.

Any general conclusion as to the contributions of this process to industry, its credits and its debits, must be qualified by consideration of the motives which lead to its specific application. That the process has added vastly to the reserves of materials thus made available for cement manufacture is obvious. As at Valley Forge and in the Lehigh Valley district, the process enables the manufacturer to produce at least three modern cements that could not otherwise be made with local materials and correctives. It has permitted the erection of cement mills near large markets where the manufacture of cement would be impossible by older methods; an illustration is the plant of the Argentine subsidiary of the Lone Star Cement Corporation at Paraná, which makes possible enormous savings in freight. In the Lehigh Valley, for example, the buying of limestone from other districts to make up the deficiency in calcite is one of the largest items of cost.

Against these advantages are the initial cost of the processing plant and its operating costs. The fixed charges are increased to about the cost of the cell house and its equipment, because the cost of the necessary classifiers and thickener is about offset by equivalent classifier and thickener capacity required for a modern closed-circuit wet-grinding system. The power and the reagents required for the operation of the flotation cells is a new item, but this may be more than recovered by unexpected savings. Thus, if the minerals are relatively coarse, as at Valley Forge, the savings in raw grinding, clinker burning, and grinding of the finished cement about balance the new items; but savings in quarrying and handling, now that careful preliminary selection of rocks is no longer necessary,

-10 μ fraction-74 + 44 μ fraction

**Comparison between Fractions of Different Particle Sizes
Separated from Ground Lehigh Valley Cement Rock.**

The composite particle at the upper left of the coarse fraction is typical of incomplete mineral bond breakage in the + 20 μ fractions.

are always substantial. Grinding savings are not necessarily merely equivalent to modern closed-circuit methods, as demonstrated at Paraná where the coarse quartz is discarded prior to final grinding. The rejects involve a loss of power, but they are largely undesirable minerals and useless; if they are relatively coarse their value is less than that of the power that would be consumed in reducing them to sizes appropriate for burning. These rejects may have by-product value; a plant at Pargas, Finland, has been separating calcite from wollastonite, and the latter has been sold to a glass plant. From the point of view of the cement chemist, the ability, for the first time, accurately to control the proportions and ratios of the several constituents completely overshadows all other factors.

With respect to other possible uses in industry, probably the most significant results are the successful separations and recoveries made from mixed minerals of extreme fineness which were heretofore not thought to be amenable to flotation concentration, the depression of graphitic carbon, and the recovery of industrial minerals of low intrinsic value, all within the range of practical economics. The successful concentrations made from flotation pulps of such extreme fineness seem to indicate that useful recoveries or differential separations can be made both from low-grade ceramic materials, such as sands and clays, and from non-metallic materials other than calcite. With special reference to non-metallic materials such recoveries might be made both from the fine-particle-size fractions or slimes, now separated from flotation pulps and discarded as a preliminary waste product, and from ores now neglected because of the fineness of crystallisation.

The industrial development of the process is due in large measure to the co-operative research of the Valley Forge Cement Company and its associated company, the Separation Process Company, the Dorr Company, and the American Cyanamid Company. Important contributions have been made by the laboratory of F. L. Smidt & Co., who have applied the process to several cement mills. Acknowledgment is made of the assistance of E. I. du Pont de Nemours & Company in the development of cationic flotation reagents useful in these alkaline pulps.

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Specification for Limes.

THE British Standards Institution has issued a Standard Specification (No. 890—1940) for Building Limes, copies of which may be obtained from the Institution (price 3s. 6d.). Eminently hydraulic limes, natural cements, and lime ashes are not dealt with in the Specification. In a foreword, it is stated that it is recognised by the committee that the operations to which the material is subjected under the clauses of the specifications are generally very different from those employed in building contracts. These differences are unavoidable, owing first to the necessity of laying down test methods which are rigidly standard and so capable of giving a closely reproducible result, and secondly to the need of utilising properties susceptible to exact measurements. The methods of test employed in the specifications are those which the examination of a large number of limes, representing many types and qualities, has shown to give a clear indication of the quality of the lime under examination, and that it possesses the properties desirable in a lime required for use in building operations.

Quicklimes are divided into two groups: *A*, Quicklime for plastering finishing coat, coarse stuff, and building mortar, and *B*, Quicklime for coarse stuff and building mortar only. Either class may be of the non-hydraulic or of the semi-hydraulic type respectively.

Quicklime sold under the specification must consist essentially either of calcium oxide, or of calcium oxide together with a smaller proportion of magnesium oxide, formed by burning natural rock or other suitable material at such a temperature that it will slake when brought into contact with water. The calcium and magnesium compounds present in the lime, and calculated as oxides, must be not less than 70 per cent. by weight of the ignited sample. The remainder must be essentially composed of silica and alumina which are soluble when treated in the manner described in an appendix to the specification. If the magnesium oxide exceeds 5 per cent. by weight of the ignited sample, the lime is to be termed a magnesium lime.

In the case of quicklime for plastering finishing coat, coarse stuff, and building mortar (Class A), the material must comply with specified requirements for: (i) Content of calcium and magnesium oxides; (ii) Loss on ignition; (iii) Content of carbon dioxide; (iv) Content of insoluble matter; (v) Residue on slaking; (vi) Volume yield; (vii) Workability. Lime of the semi-hydraulic type must also comply with a hydraulic strength requirement.

When the lime is sampled the loss on ignition must not exceed 5 per cent. by weight in the case of lump quicklime, or 7 per cent. by weight in the case of ground quicklime. When the lime is sampled elsewhere than at the works of the manufacturer, the content of carbon dioxide must not exceed 7 per cent. by weight. The insoluble matter must not exceed 3 per cent. by weight. The quicklime must leave not more than 5 per cent. by weight on a B.S. sieve No. 18, and after passing through B.S. sieve No. 18 not more than 2 per cent. by weight shall remain on a B.S. sieve No. 52. The lime must have a degree of hydraulic strength indicated

by a modulus of rupture of not less than 100 lb. per sq. in. and not more than 300 lb. per sq. in. at 28 days.

Quicklime for coarse stuff and building mortar only must comply with specified requirements for : (i) Content of calcium and magnesium oxides ; (ii) Loss on ignition ; (iii) Content of carbon dioxide ; (iv) Content of insoluble matter ; (v) Residue on slaking ; and, in the case of the semi-hydraulic type, (vi) Hydraulic strength. When the lime is sampled at the works of the manufacturer, the loss on ignition must not exceed 5 per cent. by weight in the case of lump quicklime, and 7 per cent. by weight in the case of ground quicklime. When the lime is sampled elsewhere than at the works of the manufacturer, the content of carbon dioxide must not exceed 7 per cent. by weight. The insoluble matter must not exceed 3 per cent. by weight. The quicklime must leave not more than 5 per cent. by weight on a B.S. sieve No. 18. Semi-hydraulic quicklimes must have a degree of hydraulic strength indicated by a modulus of rupture of not less than 100 lb. per sq. in. and not more than 300 lb. per sq. in. at 28 days.

The classification of hydrated limes is as follows : Class A, Hydrated lime for plastering finishing coat, coarse stuff, and building mortar ; Class B, Hydrated lime for coarse stuff and building mortar only. Either class may be of the non-hydraulic or of the semi-hydraulic type. Dry hydrated lime must be in the form of a fine dry powder produced by treating quicklime with sufficient water in any suitable form so as to produce a dry and sound product. The quicklime employed must consist essentially either of calcium oxide, or of calcium oxide together with a smaller proportion of magnesium oxide, formed by burning a natural rock or other suitable material at such a temperature that it will slake when brought into contact with water. The calcium and magnesium compounds present, calculated as oxides, must be not less than 70 per cent. by weight of the ignited sample. The remainder must be essentially soluble silica and alumina. If the magnesium oxide exceeds 5 per cent. of the ignited sample the lime shall be termed a magnesian lime.

Hydrated lime for plastering finishing coat, coarse stuff, and building mortar (Class A) must be such that the specified requirements are complied with in respect to the following : (i) Content of calcium and magnesium oxides ; (ii) Content of carbon dioxide ; (iii) Content of insoluble matter ; (iv) Workability ; (v) Fineness ; (vi) Soundness ; and, in the case of the semi-hydraulic type, (vii) Hydraulic strength.

In addition to complying with the requirements already mentioned, the material must also conform to the following : (i) The content of carbon dioxide must not exceed 5 per cent. by weight ; (ii) The insoluble matter must not exceed 1 per cent. by weight. The hydrated lime must not leave more than 5 per cent. by weight on a B.S. sieve No. 72, and after passing the B.S. sieve No. 72 not more than 10 per cent. by weight must remain on a B.S. sieve No. 170. Both calculations are to be based on the weight of the hydrated lime taken.

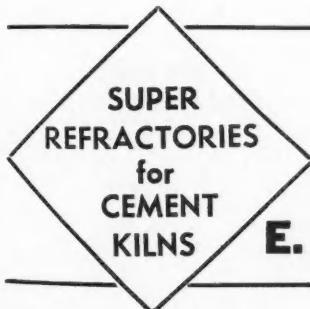
In the case of semi-hydraulic lime only the lime must have a degree of hydraulic

strength indicated by a modulus of rupture of not less than 100 lb. per sq. in. and not more than 300 lb. per sq. in. at 28 days.

Hydrated lime for coarse stuff and building mortar only (Class B) must comply with specified requirements in respect to the following : (i) Content of calcium and magnesium oxides ; (ii) Content of carbon dioxide ; (iii) Content of insoluble matter ; (iv) Fineness ; (v) Soundness ; and, in the case of the semi-hydraulic type, (vi) Hydraulic strength.

In addition to complying with the foregoing requirements, the material must also conform to the following : (i) The amount of carbon dioxide must not exceed 5 per cent. by weight ; (ii) The insoluble matter must not exceed 1 per cent. by weight. The lime must not leave more than 5 per cent. by weight on a B.S. sieve No. 72, and after passing the B.S. sieve No. 72 not more than 10 per cent. by weight must remain on a B.S. sieve No. 170. Both calculations are to be based on the weight of the hydrated lime taken. When tested for soundness, none of the Le Chatelier moulds shall exhibit an expansion greater than 10 mm. In the case of semi-hydraulic limes only, the lime must have a degree of hydraulic strength indicated by a modulus of rupture of not less than 100 lb. per sq. in. and not more than 300 lb. per sq. in. at 28 days.

Appendices to the Specification describe (1) Methods of sampling ; (2) Determination of loss on ignition ; (3) Determination of insoluble matter ; (4) Method of isothermal slaking ; (5) Determination of residue on slaking ; Determination of fineness ; (6) Adjustment to standard putty and determination of volume yield ; (7) Preparation of lime putty of standard plastering consistency ; (8) Description of standard flow-table, method of operation and method of carrying out tests for consistency and workability ; (9) Description of gauging plaster ; (10) Standard sand ; (11) Determination of soundness ; (12) Preparation of standard 3 : 1 sand-lime mortar ; (13) Determination of hydraulic strength ; (14) Specification limits.



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Ball-Mill Grinding.*

Type of Grind with Different Amounts of Ore Charges in Wet and Dry Ball Milling.—*Table 17* is compiled from *Tables 13* and *14*, the object being to facilitate a ready comparison of types of grind in the wet and dry work. The conclusions to be drawn are not in harmony with some of those in the literature where experimental evidence was too scanty to justify the broad statements that were made. Such statements have prompted the compilation now to be discussed.

TABLE 17.—TYPE OF GRIND WITH DIFFERENT AMOUNTS OF ORE IN WET AND DRY BALL MILLING (CHERT AT TOP, DOLOMITE AT BOTTOM.)

(Mill, cylindrical, 19 in. by 36 in. Circuit, batch. Speed, 50 per cent. critical. Ball load, Davis No. 1, 796 lb. Volume, 45 per cent. Ore charge, chert and dolomite. Consistency, wet and dry.)

Size, mesh	Feed, weight percent	Products, weight percent													
		200 lb.		150 lb.		125 lb.		100 lb.		75 lb.		50 lb.		35 lb.	
		Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
10	25.2	0.4	1.7	0.3	1.4	0.4	1.8	0.5	1.3	1.6	1.2	3.7	1.4	4.5	2.3
14	55.0	3.3	9.3	3.2	8.1	3.1	8.4	3.2	6.6	6.0	17.2	10.4	6.2	12.4	8.7
20	76.7	14.0	24.3	13.1	21.1	12.8	22.1	12.2	18.0	16.0	17.2	20.7	16.5	21.5	21.0
28	87.2	30.0	39.8	28.4	36.4	28.3	37.6	27.8	32.8	30.9	32.1	33.0	30.7	34.5	34.2
35	93.4	48.8	52.6	46.7	49.8	46.9	51.3	46.9	47.1	48.2	47.1	49.4	45.4	49.6	48.7
48	96.2	60.5	62.8	58.7	60.6	59.0	62.4	59.8	59.1	61.0	59.9	61.1	58.2	60.5	61.1
65	97.9	70.7	70.6	68.8	69.0	69.2	70.7	70.5	68.2	70.9	69.5	71.0	67.9	69.9	70.5
100	98.9	77.7	77.6	76.3	76.4	76.6	78.0	77.8	76.2	78.1	77.9	78.2	76.4	77.2	78.5
150	99.4	83.1	82.0	82.0	81.2	82.2	82.6	83.2	81.4	83.3	83.1	83.5	81.8	82.5	83.5
200	99.6	86.4	85.5	85.5	84.9	85.9	86.1	86.6	85.3	86.5	87.0	86.9	85.9	87.1	
-200	.4	13.6	14.5	14.5	15.1	14.1	13.9	13.4	14.7	13.5	13.0	13.1	14.2	14.1	12.9
10	15.3	0.6	2.9	0.6	2.2	0.6	2.1	0.5	2.0	1.8	2.1	3.6	1.8		2.1
14	50.8	6.4	15.6	5.8	12.5	5.9	12.5	5.8	11.8	10.7	11.4	16.2	10.3		11.2
20	79.5	20.9	35.5	20.0	31.2	19.8	31.1	19.5	26.6	27.0	29.1	32.5	27.1		27.9
28	90.2	37.7	51.1	36.8	47.0	36.0	47.5	36.7	46.1	42.9	45.4	46.4	43.1		44.1
35	95.4	63.7	70.0	53.3	58.9	52.5	59.9	53.8	58.4	58.1	57.7	59.1	56.0		56.8
48	97.3	62.8	69.6	62.5	65.7	61.8	67.3	65.7	63.5	67.2	66.6	66.9	66.5	65.4	
65	98.2	69.5	74.5	69.2	73.0	68.6	74.3	70.6	73.2	73.0	73.1	72.2	71.7		72.5
100	98.6	74.9	78.8	74.0	78.1	74.2	79.2	76.0	78.4	77.8	78.3	76.9	77.7		78.0
150	98.8	79.2	81.8	78.8	81.7	78.7	82.6	80.1	82.0	81.6	82.1	80.8	81.1		81.7
200	99.0	82.6	84.6	82.0	84.9	82.4	85.6	83.3	85.3	84.5	85.3	83.8	84.7		85.0
-200	1.0	17.4	18.4	18.0	15.1	17.6	14.4	16.7	14.7	15.5	14.7	16.2	15.3		15.0

The size analyses of wet grinding at 50 per cent. speed in *Table 13* have been brought together with those of dry grinding in *Table 14* at the same speed. The upper part of the table is for chert and the lower part for dolomite. Throughout the table it holds true that with the heavy ore charge the coarse particles were reduced more in wet than in dry grinding. The reverse is true when the ore charge is light. Midway, that is at about 75 lb. of ore, the degree of selective grinding was about the same. With this charge, closed-circuit work would be expected to develop the same type of circulating load whether wet or dry. In wet grinding the heavy ore charge in the mill would give a

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closed-circuit product with the minimum amount of coarse particles, but in dry grinding the advantage would be in favour of the small ore charge.

Wet and Dry Open-circuit Ball Milling.—The results shown in *Table 18* are from continuous open-circuit work done to compare wet and dry grinding. First, it must be said that by choice the grinding was more intense than in former work—only 0.171 ton and 0.132 ton per horsepower-hour, wet and dry, respectively, whereas in much of the earlier grinding of dolomite it was about 0.60 ton per horsepower-hour. The small tonnage treated per unit of power accounts for the large amount of the subsieve sizes. The feeds were

TABLE 18.—WET AND DRY BALL MILLING COMPARED.

(Mill, cylindrical, 19 in. by 36 in. Circuit, continuous, open. Discharge, 8 in. Speed, 70 per cent. critical. Ball load, rationed, No 1. Volume, 45 per cent. Ore charge, dolomite. Consistency, wet and dry.)

Size, mesh	Feed, weight percent	Product, weight percent	
		Wet, 60 per cent solids	Dry
8	0.9	0.3	0.1
10	15.3	2.4	.8
14	50.8	5.8	2.1
20	79.5	8.5	3.9
28	90.2	10.8	6.3
35	95.4	13.5	9.8
48	97.3	17.4	15.7
65	98.2	23.0	23.8
100	98.6	32.1	33.8
150	98.8	41.4	42.5
200	99.0	51.6	51.1
—200	1.0	48.4	48.9
Surface tons per hour		100.2	73.7
Surface tons per horsepower-hour		51.7	40.3
Ton per hour		.831	.242
Horsepower		1.94	1.84
Ton per horsepower-hour		171	.132

adjusted for the close correlation of the minus 200-mesh sizes and the feed rates determined.

Only a slight difference is shown between the type of the wet and dry grinds; the selective grinding was a little better in the dry work. The difference is in accord with the right side of *Table 17*, where a small ore charge received the better selective grinding when the feed was dry. The ore charge in the tests shown in *Table 18* would probably be small because the mill, which was 19 in. in diameter, had an 8-in. discharge. Wet grinding gave 39 per cent. more capacity and 26 per cent. more efficiency than dry grinding. These values supplement those shown in *Table 16*.

(*To be continued.*)

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- (b) **From Employers** that they would undertake not to use evidence of the ability of workpeople to save as an argument against applications for wage advances.

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